Movements of bull trout (*Salvelinus confluentus*), spring chinook (*Oncorhynchus tshawytscha*), and steelhead (*Oncorhynchus mykiss*) in Icicle Creek, Washington

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INTRODUCTION

The Leavenworth National Fish Hatchery (LNFH), built in 1939-40, is located on Icicle Creek, Washington. The original design of the hatchery involved diverting the majority of Icicle Creek's flow through a canal with an energy control dam at the base and construction of holding dams and weirs in the original creek channel. These structures effectively block fish passage to the upper Icicle and are no longer needed for hatchery operations. Migration of threatened bull trout, spring chinook, endangered steelhead, and many other fish species are affected.

The U.S. Fish and Wildlife Service (USFWS) in cooperation with the U.S. Forest Service (USFS) has initiated a National Environmental Policy Act (NEPA) process to address fish passage at LNFH. An Environmental Impact Statement (EIS) is being prepared to present a range of alternatives for providing riverine fish passage past the main hatchery complex and assessing, if implemented, their affect on the baseline environment. In the process of developing alternatives, further research needs were identified. One identified need is to determine how far fish will migrate upstream if passage is provided at LNFH. There are several potential man-made and natural fish passage barriers in Icicle Creek above LNFH. To address this need a radiotelemetry project was developed and implemented in 1999. In both 1999 and 2000, radio transmitters were implanted in 20 steelhead and 15 spring chinook. Also in 2000, five bull trout were tagged. Most of these fish were placed above LNFH and below all potential man-made and natural barriers and radio-tracked.

STUDY AREA

Icicle Creek is a fourth order tributary to the Wenatchee River (Figure 1). It is 31.8 miles long and drains a 211 square mile basin containing 14 glaciers and 102 lakes. The USFS manages 87% of the Icicle Creek catchment and the remaining area is in private ownership. Icicle Creek and the Wenatchee River watersheds have a long history of man-made and natural disturbances. Both rivers are on the Washington State 303(d) list for not meeting temperature, dissolved oxygen, pH, and instream flow standards (WRWSC 1998).

The flow in Icicle Creek ranges from a minimum of 44 cfs to a maximum of 14,100 cfs according to readings taken from the USGS gaging station located above all the major diversions. The flow of Icicle Creek is altered by water diversions which can reduce the flow in the lower reaches to very low levels during the summer and early fall. The City of Leavenworth and the Icicle Irrigation District divert water above the Snow Lakes trail head and the LNFH and Cascade Irrigation Company divert water below the trail head. Irrigation diversions remove 48% and 79% of the mean August and September flows, respectfully (Mullan *et al.* 1992). To assure cold water for the LNFH in dry summers, a supplementary water supply (16,000 ac-ft) was developed in Upper Snow Lake, about seven miles from LNFH and one mile above it in elevation. Without the releases (50 cfs) from Upper Snow Lake, the downstream reaches of Icicle Creek would go dry in some years. In addition to low flows, the diversion dams themselves may present fish

passage problems. There are also several natural fish passage obstacles in Icicle Creek above LNFH (Figure 2). However, none have been scientifically proven to be year-round fish migration barriers.

Other impacts in Icicle Creek's watershed include logging, urban development, recreation, fires, and landslides. Five percent of Icicle Creek's watershed has been directly impacted by logging (USFS 1994). The 1994 forest fires burned 12% of the watershed (USFS 1994). During the first week of June 1999, a scarp failure at 4800 feet in elevation introduced a large sediment load into Icicle Creek. The scarp was approximately 120 ft wide, 300 ft long, and 10-15 ft thick slid (Matt Karrer pers. comm.). Over 11% of the vegetation along lower Icicle Creek has been removed (WRWSC 1998). Extensive road building has occurred for development, recreation, and timber harvest. The Icicle Creek watershed is a popular recreation area for hikers, climbers, fishermen, and many others.

Fish species present in the Icicle above and/or below LNFH include various members of the Salmonidae, Catostomidae, Cottidae, and Cyprinidae families. Threatened and endangered species present include bull trout (*Salvelinus confluentus*), non-hatchery stock spring chinook (*Oncorhynchus tshawytscha*), and steelhead (*Oncorhynchus mykiss*). Critical habitat, including Icicle Creek, is designated for spring chinook and steelhead. Federal species of concern include Pacific lamprey (*Lampetra tridentata*), redband trout (*Oncorhynchus mykiss gairdneri*), and westslope cutthroat trout (*Oncorhynchus clarki lewisi*).

** Throughout the discussion the text may refer to the "lower" and "upper" Icicle and the original (historic) channel. The lower Icicle refers to the portion of the creek below LNFH (river mile (rm) 0-2.8), upper Icicle refers to the creek above LNFH (rm 3.8 and above), and the original channel refers to the section of Icicle Creek on LNFH that has been sectioned off by dams and weirs with a bypass canal running along side it (rm 2.8-3.8).*

STUDY SPECIES

Bull Trout (*Salvelinus confluentus*)

Bull trout, members of the family Salmonidae, are char native to the Pacific Northwest and western Canada. Bull trout are estimated to have occupied about 60% of the Columbia River basin, and presently occur in 45% of the estimated historical range (Quigley and Arbelbide 1997). Bull trout have declined in overall range and numbers of fish. Though still widespread, there have been numerous local extirpations reported throughout the Columbia River basin. Although some strongholds still exist, bull trout generally occur as isolated subpopulations in headwater lakes or tributaries where migratory fish have been lost. The Columbia River distinct population segment of bull trout was listed as threatened under the Endangered Species Act (ESA) on June 10, 1998.

Bull trout exhibit resident and migratory life-history strategies through much of their current range (Rieman and McIntyre 1993). Resident bull trout complete their life cycle in tributary streams in which they spawn and rear. Migratory bull trout spawn in tributary streams where juvenile fish rear from one to four years before migrating to either a lake (adfluvial); river (fluvial), or in certain coastal areas, to saltwater (anadromous), where maturity is reached in one of the three habitats (Fraley and Shepard 1989; Goetz 1989).

Bull trout have relatively specific habitat requirements compared to other salmonids (Rieman and McIntyre 1993). Habitat components that appear to influence bull trout distribution and abundance include water temperature, cover, channel form and stability, valley form, spawning and rearing substrates, and migratory corridors (Oliver 1979; Pratt 1984, 1992; Fraley and Shepard 1989; Goetz 1989; Hoelscher and Bjornn 1989; Sedell and Everest 1991; Howell and Buchanan 1992; Rieman and McIntyre 1993, 1995; Rich 1996; Watson and Hillman 1997). Watson and Hillman (1997) concluded that watersheds must have specific physical characteristics to provide the necessary habitat requirements for bull trout to successfully spawn and rear and that the characteristics are not necessarily ubiquitous throughout watersheds in which bull trout occur. Because bull trout exhibit a patchy distribution, even in pristine habitats (Rieman and McIntyre 1993), they should not be expected to simultaneously occupy all available habitats (Rieman *et al.* 1997). Water temperatures above 15° C (59° F) limit bull trout distribution, which partially explains their generally patchy distribution within a watershed (Fraley and Shepard 1989; Rieman and McIntyre 1995).

Preferred spawning habitat consists of low gradient streams with loose, clean gravel (Fraley and Shepard 1989) and water temperatures of 5 to 9° C (41 to 48° F) in late summer to early fall (Goetz 1989). Spawning areas are often associated with cold-water springs, groundwater infiltration, and the coldest streams in a given watershed (Pratt 1992; Rieman and McIntyre 1993; Rieman *et al.* 1997).

Bull trout typically spawn from August to November during periods of decreasing water temperatures. In the Wenatchee River basin bull trout spawn in September to October. However, adult migratory bull trout frequently begin spawning migrations as early as April, and have been known to move upstream as far as 250 kilometers (km) (155 miles (mi)) to spawning grounds (Fraley and Shepard 1989).

The Icicle Creek bull trout population is one of ten stocks in the Wenatchee River watershed. All bull trout in the Wenatchee River watershed are native, as no hatchery introduction of bull trout has occurred (WDFW 1997). The Icicle Creek population is a distinct stock which is isolated from other stocks mainly by water temperature and the LNFH spillway dam (river mile (rm) 2.8). Stock population status is unknown (WDFW 1997). Both resident and migratory life histories exist in this population. Resident fish are isolated above the LNFH dam. Adult fluvial bull trout return to the base of the dam and may be recruits from resident fish above the dam or adults holding or straying from the Wenatchee River (WDFW 1997). A few bull trout may arrive to the spillway pool as early as July but most arrive mid-August to early September.

Key factors affecting Icicle Creek's bull trout population are thermal isolation, isolation due to fish barriers, irrigation withdrawals (screened and unscreened), high water temperatures, extensive human and natural impacts in the watershed, and competition and hybridization with introduced fish species (WDFW 1997).

Snorkel surveys conducted by USFWS staff revealed 8 bull trout in 1996, 6 bull trout in 1997, 40 in 1998, 7 in 1999, and 40 in 2000 in the pool below the hatchery spillway dam. Snorkel surveys were conducted later into the year beginning in 1998. USFWS (1997) reported observing, in 1994, seven bull trout in upper Icicle Creek and four bull trout in the tributary Jack Creek (rm 17.2). In 1938 twelve Dolly Varden (bull trout) were collected in the bypass trap of the Icicle irrigation ditch at rm 5.7. (Brennan 1938).

For this study, five bull trout were captured in 2000 by hook and line from the spillway pool, surgically implanted with transmitters, and released into Icicle Creek above the hatchery.

Chinook Salmon *(Oncorhynchus tshawytscha)*

The Upper Columbia River spring chinook salmon evolutionarily significant unit (ESU) is listed as endangered under the Endangered Species Act (ESA) and critical habitat for this ESU is designated. This ESU includes stream-type chinook salmon spawning above Rock Island Dam in the Wenatchee, Entiat and Methow Rivers. Only naturally spawned chinook salmon are listed at this time. The brood stock returning to LNFH is considered an out-of-basin stock and is not listed.

Threats to the chinook salmon ESUs include watershed development such as forest practices, mining, agricultural land use, urbanization, hydropower development, and water manipulation and withdrawal. Over fishing, artificial propagation, and introduction of nonnative species has also impacted chinook salmon ESUs. Forest practices, mining, agricultural land use, urbanization, hydropower development, and water withdrawal have resulted in increased sedimentation, changes in flow regimes and channel morphology, decreases in water quality and quantity, loss of riparian habitat, loss of large woody debris and recruitment, higher water temperatures, decreased gravel recruitment, reduction in pools and spawning and rearing areas, rerouting of stream channels, degradation of streambanks and loss of estuarine rearing areas (Bishop and Morgan 1996, Myers *et al.* 1998). These changes have impacted the spawning and rearing environment of chinook salmon. Harvest and hatchery practices and the introduction of non-native species has also impacted the expression of the varied life history strategies of chinook salmon within these ESUs.

Stream-type chinook salmon, which is characteristic of spring fish (Spence *et al.* 1996), reside as fry or parr in freshwater for a year or more before migrating to sea. They perform extensive offshore oceanic migrations and return to their natal river during the spring and early summer, several months prior to spawning. (Healey 1991). Stream-type chinook salmon tend to enter freshwater as immature or "bright" fish, migrate far upriver, and use upper watersheds for

spawning in late summer and early autumn (Myers *et al.* 1998).

Spring chinook entering Icicle Creek are primarily adults returning to LNFH. One stray from the wild Chiwawa River stock entered LNFH in 1994. LNFH has raised spring chinook since 1940. The adult broodstock returns to the hatchery from mid-May to mid-July and spawning begins in mid-August. Spring chinook returning to Icicle Creek not only provide the broodstock for LNFH but also allow for a sport and tribal fishery.

Spring chinook also spawn in the lower Icicle below the hatchery. These spawners are thought to be of hatchery origin (Peven and Mosey 1996). From 1989-1993 an average of 41 (range = 24-53) and from 1994-1999 an average of 14 (range = 6-33) spring chinook redds were counted in lower Icicle Creek below LNFH (Mosey and Truscott 1999; Mosey pers. comm.).

For this study, fifteen spring chinook in 1999 and again in 2000 were captured from the hatchery's adult return ladder and holding ponds, tagged, and released above the hatchery.

Steelhead trout (*Oncorhynchus mykiss*)

The Upper Columbia River steelhead ESU was listed as endangered under the ESA in August 1997 (NMFS 1997). Critical habitat for this ESU was designated in February 1999 (NMFS 1999). The NMFS is listing only the anadromous life forms of *O. mykiss* in this ESU (NMFS 1997). Only naturally spawned populations of steelhead and their progeny which are part of the biological ESU residing below long-term, natural and man-made impassable barriers are listed (NMFS 1997). The Wells Hatchery stock of steelhead is included as listed in this ESU because it is essential for recovery, as it probably retains the genetic resources of steelhead populations above Grand Coulee Dam that are now extinct from their native habitats (NMFS 1997).

Threats to steelhead trout include: grazing, water diversions, hydroelectric development, forestry and associated road building (Yee and Roelofs 1980; Platts 1981; Chamberlin 1982) contributing to habitat degradation (Busby *et al.* 1996); failure of natural stocks to replace themselves, genetic homogenization due to hatchery supplementation; and high harvest rates on steelhead smolts in rainbow trout fisheries.

The Upper Columbia River steelhead ESU occupies the Columbia River basin upstream from the Yakima River, and includes the Wenatchee, Entiat, Methow and Okanogan river basins (Busby *et al.* 1996). For Columbia River basin inland populations, total age at maturity is 4 years with 2 years in freshwater, 1 year in the ocean and 1 year in freshwater as an adult prior to spawning (Busby *et al.* 1996). All upper Columbia River steelhead are summer steelhead (Busby *et al.* 1996). Summer steelhead enter fresh water from May to October in a sexually immature state, migrate upstream during the spring and summer, and hold in areas of protected cover such as deep pools , undercut banks, overhanging vegetation or large woody debris or boulder structures until they become sexually mature. These summer steelhead do not spawn until the following spring (Pauley *et al.* 1986), so they hold over the fall and winter in freshwater. Steelhead along

with cutthroat trout can spawn more than once (iteroparity), all other species of *Oncorhychus* spawn once and then die (semelparity). North of Oregon, repeat spawning is relatively uncommon and more than 2 spawning migrations is rare. Iteroparity occurs predominantly in females (Busby *et al.* 1996).

Steelhead returning to Icicle Creek from the ocean travel 497 miles (800 km) and must negotiate 7 Columbia River dams. The population size of wild steelhead in Icicle Creek is unknown. In 2000 the Washington Department of Fish and Wildlife (WDFW) conducted a steelhead spawning ground survey in the lower Icicle from March 23rd to May 20th. Twenty redds and 20 adults were observed with an estimated total number of adult steelhead in lower Icicle Creek ranging from 40 to 50 (Viola pers. comm.). In 1937 one hundred and seven steelhead were collected in the Icicle irrigation ditch (Brennan 1938). Fulton (1970) listed Icicle Creek below LNFH and the mainstem Wenatchee as steelhead spawning grounds. Mullan *et al.* (1992) states that the life history plasticity of steelhead explains why headwater populations of resident *O. mykiss* above LNFH continue to produce steelhead.

LNFH raised summer steelhead from 1940-1951 and from 1977-1995 with the last release in 1997. The hatchery steelhead returned from late March to early April and were spawned in mid-May. The first release of hatchery steelhead into Icicle Creek occurred in 1941. Between 1978 and 1997, a total of 1,372,789 steelhead were released into Icicle Creek. All releases occurred below the hatchery. Also, since 1982, the Washington Department of Fish and Wildlife (WDFW) has released 331,657 hatchery summer steelhead into Icicle Creek, either at or below LNFH and approximately 3.7 million into the Wenatchee Basin. All hatchery produced steelhead since 1986 have been marked by adipose fin clipping before release. The percentage of wild steelhead in the adult returns to LNFH for the years 1987, '88, '91, and '93 averaged 21% (range = 4-41%) (USFWS 1998).

For this study, thirty-two steelhead in1999 and twenty-seven in 2000 were captured in the ladder at LNFH. Four of the steelhead captured in 1999 and one of the steelhead captured in 2000 were not adipose fin clipped and may have been of wild origin. All other captured steelhead were adipose clipped and were of hatchery origin. Twenty of the captured steelhead, in both years, were radio tagged and all were placed above LNFH.

METHODS

Fish Handling

In 1999, thirty-two migratory steelhead (twenty radio tagged) and 15 spring chinook were captured in the LNFH fish ladder at the top of the spillway pool (Figure 3). In 2000, twenty-seven steelhead (20 tagged) and 15 spring chinook were captured in the ladder. Also in 2000, five bull trout were captured by hook and line from the spillway pool. Captured fish were placed in a large tank with oxygenated water until they could be processed. Each fish was processed

individually. Fish were placed in a second tank and anaesthetized. Bull trout and steelhead, exempt from retention in fisheries, were anaesthetized with Tricaine Methane Sulfonate (MS-222; $C_{10}H_{15}NO_5S$). Spring chinook, which could be retained during a fishery, were anaesthetized with carbon dioxide (CO_2). The extent to which fish were exposed to the anesthetic bath was dependent on the transmitter insertion procedure. Steelhead and spring chinook were brought to stages 3 or 4 as described in the Stages of Anesthesia by Summerfelt and Smith (1990). Since the surgical insertion of the transmitters for bull trout is a more invasive procedure, they were brought to stage 5, which consisted of slow and irregular opercular movements. Each fish was given a number and the date and time captured and processed, fork length, sex, and transmitter channel and code were recorded. All coded microprocessor transmitters were checked for transmission before they were inserted into a fish. A tissue sample of the caudal fin of bull trout and steelhead were removed and placed in a vial containing 100% ethanol and labeled. These specimens were sent to genetics labs for analysis to determine stock origin. Previous fin clips and fish health were noted. For spring chinook and steelhead, a ring of surgical tubing was placed around a transmitter, it was then gently pushed through the fish's esophagus (Figures 4 & 5). Transmitters were surgically inserted into bull trout (Figure 6). Surgery involved placing a bull trout on its dorsum in a V-shaped holder; making an approximately 1 inch (2.5 cm) incision anterior to the pelvic fins, slightly to the side of the mid-ventral line; inserting a hollow needle through the body wall, from the outside to the inside; threading a transmitter's antennae through the hollow needle from the inside out; removing the needle while keeping the antennae in place; gently inserting the transmitter into the body cavity; and finally closing the incision using 2-3 independent sutures. For further detail on both transmitter insertion procedures see McKinley *et al.* 1992. The fish were then placed into a tote for recovery observations. Once the fish had sufficiently recovered, it was placed into a fish tube and held in a large tank, in the back of a truck, containing oxygenated water. Total processing time per fish ranged from 5 to 15 minutes. After all fish were processed, they were driven to a release site. At the release site, the fish inside the fish tubes were placed in the stream and secured to the bank. The fish tubes were monitored to protect them from being tampered with. After approximately 1 hour of recuperation and acclimation, the fish were released.

Release Sites

Several release sites were used in 1999 and 2000. In 1999, a total of 25 steelhead, 17 of which were radio tagged, and all 15 spring chinook were released at the top of the LNFH canal approximately 0.8 miles upstream from the collection site. This release site is located below all potential man-made and natural fish barriers and was chosen to optimize information on fish passage problems. An additional seven steelhead (3 radio tagged) were released at eightmile campground. This release site is located at river mile 9 in the upper Icicle. In 2000, the first four steelhead were released just upstream of LNFH property off the Icicle River RV Park. This site was used because of low flow conditions in the canal. All fifteen spring chinook, the remaining twenty-three steelhead, and four bull trout were released at the top of the LNFH canal. One additional bull trout was radio tagged and released into the pool just above the LNFH intake approximately 1.5 miles upstream of the collection site due to low flow conditions.

Tracking

Lotek SRX_400 receiver/data logger models W5 (mobile) and W17AS (fixed) were used to track fish movement. For mobile tracking, three location attempts were made for each fish each week in the daytime. They were first located by driving the road parallel to the creek. Their exact location was pinpointed by walking parallel to Icicle Creek. The fish's position was then identified to within $1m^2$ through triangulation. This method was practiced before the project began. If fish were not located above the LNFH main complex, the lower Icicle and the Wenatchee River, between the Icicle Road bridge and the Leavenworth Highway 2 bridge was checked. Radio tagged fish in lower Icicle Creek can't be thoroughly tracked from the road system. Thus, the lower Icicle and part of the Wenatchee River was floated as necessary to track fish that had moved below LNFH. GPS coordinates of the fish's position were recorded and the position was marked on a USGS 7.5' map and flagged near the bank.

For constant tracking, a fixed station was placed on Wenatchee National Forest property approximately 1 river mile above the Snow Creek parking lot. This site is also upstream of the "boulder area" at river mile 5.6, the first natural, potential fish obstacle.

The fixed receiver connected to a deep cell marine battery was placed in a locked metal box chained to a large tree to prevent being tampered with (Figure 7). Two antennas were secured to the same tree and were positioned to detect movement of fish migrating upstream and downstream (Figure 8). Once a week the station was visited to make sure it had not been tampered with and was working properly. The data collected by the fixed station was downloaded and the battery changed bimonthly.

Study Protocol Affects

It is unlikely that the experimental protocol influenced fish movement and behavior. Transmitters never exceeded 2% of a fish's body weight, as recommended by (Winter 1983). Precautions were taken in fish handling to minimize stress. All fish were healthy and in good condition when released. When tracking, it was not necessary to get close to a fish's position to triangulate its location and thus fish were not startled and avoidance behavior was unnecessary. No direct mortality or harm occurred to fish used in this study.

RESULTS

Bull trout

In 2000, five bull trout ranging in size from 14.6 to 19.7 inches (37 to 50 cm) and in weight from 1.17 to 3.12 pounds (0.53-1.42 Kg) were captured from August 7th through 25th and surgically inserted with transmitters (Table 1). Initial movement of three fish was in an upstream direction. The upstream terminus of these three fish was the LNFH intake area. The LNFH intake is a fish

passage obstacle at low flows. None of the bull trout were tracked above the intake. One of these three fish remained at the intake area for 14 days before migrating downstream to the Wenatchee River. This fish was last tracked on October 5, 2000 when it passed through Dryden Dam.

One fish was detected only once at the release site immediately after release. This fish was never relocated. Thus, upstream or downstream movements could not be determined.

One of the five bull trout immediately moved downstream. Ten days after release, this fish was located near Tumwater Canyon in the Wenatchee River (rm 27). For thirty days it remained in the Wenatchee River between river miles 26 and 27. This fish was last tracked on October 20, 2000 and had moved downstream to river mile 23.

Spring Chinook

In 1999, spring chinook tagged ranged in size from 28.4 to 41.3 inches (72 to 105 cm) (Table 2). Nine of the fish were female and 6 male. The fish were collected and tagged from June 8th through 22nd. Out of 15 spring chinook tagged, ten were tracked for 19-38 days and 5 were tracked for 41-83 days. Four of the fish initially moved upstream. However, all fish eventually moved downstream. Of the 5 fish in Icicle Creek during the large landslide, three moved downstream to the Wenatchee River and two entered the LNFH ladder. Once the turbidity decreased in Icicle Creek, two chinook re-entered the stream. One of the tagged spring chinook migrated past the LNFH intake and was tracked to the natural "boulder area". None were tracked past the "boulder area". Ten out of 15 spring chinook were either captured by fishermen or re-entered the hatchery's adult ponds before spawning time. Only three of the remaining five fish were tracked into August. Of these three, two were last located off the handicap access fishing dock below the LNFH pool in mid-August. The other fish migrated during August from the Icicle River RV park upstream to the natural "boulder area" and back downstream to the LNFH pool. This same fish was located off the handicap access dock during the first two weeks of September.

In 2000, spring chinook tagged ranged in size from 26.4 to 31.5 inches (67 to 80 cm) (Table 3). Eleven fish were female and four male. The fish were collected and tagged from May 24th through June 5th. Of the fifteen tagged fish, one was never relocated. Initial movements of 11 out of 14 (79%) fish were downstream of the release site. Within 48 hours of release, 4 chinook were downstream of the canal spillway. One fish, that dropped below the spillway, spent 77 days in the spillway pool and then migrated into the original Icicle Creek channel. Five of the eleven fish remained in the canal between the release site and the top of the spillway for 6 to 13 days. Four fish made initial movements upstream after their release. One fish migrated upstream to the LNFH intake 49 days after release before traveling back downstream to below the East Leavenworth Road bridge (rm 2.2). One fish was located just upstream of LNFH property for 7 days after release and then moved downstream to the spillway pool. Two fish migrated upstream to the natural "boulder area". No chinook were tracked upstream of this area.

Steelhead

In 1999, steelhead tagged ranged in size from 22.4 to 30.3 inches (57 to 77 cm) (Table 4). Nine were females and 11 male. Of the total group of steelhead captured (n=32), four were not adipose clipped and may have been wild. The steelhead were captured and tagged from April 14th through the 26th. Out of the 17 steelhead tagged (2 not adipose clipped) and released at the top of the LNFH canal, 7 were tracked for 1-16 days and 8 were tracked for 21-117 days. Two fish were never relocated. Seven out of 15 (47%) fish initially moved below the canal release site. Initial movements of 8 out of 15 (53%) fish were upstream. Five fish migrated above the LNFH intake area (approx. 0.9 mi from the release site) within 48 hours and one within 5 days of release. Out of these 6 fish, three were tracked to the natural "boulder area" within 5 days of release. No fish were tracked above the natural "boulder area". Of the 6 steelhead that were above the release site during the landslide that introduced a large quantity of sediment into the stream, 2 left the Icicle and entered the Wenatchee River and 4 were never relocated. On 5/18/99, three steelhead were located in the lower Icicle and one in the Wenatchee River. Two of these fish were visually seen on top of redds. No other fish were visually seen on or near redds.

Out of 3 steelhead tagged and released at eightmile campground in 1999, 2 were tracked for 2-7 days and 1 was tracked for 36 days. The initial movement of 2 out of 3 fish was upstream. However, these two fish stayed within 0.2 miles of their release site. The third fish was tracked 2 miles downstream. None of the fish were tracked downstream of the natural "boulder area".

In 2000, steelhead tagged ranged in size from 22.1 to 30.3 inches (56 to 77 cm) (Table 5). Thirteen of these fish were female and seven male. Of the total group of steelhead captured (n=27), one un-tagged female was not adipose clipped and may have been wild. Steelhead were captured and tagged from March 24th through April 14th. Initial movements of 7 out of 20 (35%) were upstream. Three fish migrated from the release site to the LNFH intake area within 24 hours. Two fish took 48 hours and two fish took 6 days to travel that same distance. Of these seven fish, four eventually migrated as far upstream as the "boulder area". None of the fish were tracked above this area. Initial movements of 13 out of 20 (65%) steelhead were downstream. Five of these downstream migrating fish were tracked into the original channel of Icicle Creek. Seven of the study fish migrated to lower reaches in Icicle Creek. One fish was located by Chelan Public Utility District biologists in the vicinity of Rock Island Dam approximately 10 days after release.

DISCUSSION

The goal of this project was to determine how far fish will migrate upstream if allowed to pass LNFH. There are several potential man-made and natural fish passage barriers in Icicle Creek above the hatchery. During 1999 and 2000, a total of 75 salmonids were radio tagged, placed above LNFH, and tracked. None of these fish migrated past the natural "boulder area" at river mile 5.6. The "boulder area" lies approximately 2.5 river miles above the main hatchery complex

and is a substantial velocity and gradient fish migration obstacle. This study does not prove the "boulder area" to be a fish migration barrier. However, it does show that the tagged fish did not migrate past this area during the conditions present at the time. Fish were present in the Icicle during a wide range of conditions (Table 6).

Flows during this study fell mainly within the average year hydrograph, except high flows exceeded the average of approximately 2400 cfs in both years. In 1999, the 5 year recurrence interval (RI) flood of 5,379 cfs (10 yr RI = 6,568) was exceeded (ENSR 2000).

When bull trout were present in Icicle Creek above LNFH, August 7 to 21, 2000, the flows ranged from 167-311 cfs and temperatures ranged from 55 to 60 ^{0}F. Bull trout migration in Icicle Creek may have been limited by high water temperatures. Temperatures exceeding 59 ^{0}F (15 ^{0}C) limit bull trout distribution (Fraley and Shepard 1989; Rieman and McIntyre 1995). Additionally, during September to mid-October, temperatures exceeded the preferred range for spawning 41-48 ^{0}F (5 to 9 ^{0}C). Bull trout migration may also have been limited by low flows. Bull trout in this study only migrated as far as the LNFH intake which is a fish passage obstacle at low flows. Low flows during the time of their migration may have prevented upstream passage past the intake.

When tagged spring chinook were present in the Icicle above LNFH, June 6 to August 18, 1999 and May 24 to August 24, 2000, the flows ranged from 539-5900 cfs and 159-2420 cfs, respectfully, and the temperatures ranged from 45-55 ^{0}F (7.2-12.8 ^{0}C) and 45-60 ^{0}F (7.2-15.6 ^{0}C), respectfully. Temperatures during spring chinook spawning, mid- to late August, were 55 to 60 ^{0}F (12.8-15.6 ^{0}C), exceeding the constant temperature threshold for egg deposition and normal development of 42.5 to 57.5 ^{0}F (5.8-14.2 ^{0}C). Egg viability declines acutely above and below this range (Combs and Burrows 1957). The first 72 hours is the crucial time period for chinook salmon egg development. Excessive egg mortality occurs when the initial egg incubation temperature is above the threshold even if temperatures drop to within the threshold range within a month (Johnson and Brice 1953). If tagged spring chinook had remained above LNFH and survived to spawn at temperatures above 55 ^{0}F, high egg mortality would probably have occurred (Combs 1965).

In both years, a majority of the tagged spring chinook (73 and 79%) initially moved downstream and by spawning time 93 and 100% were downstream below the hatchery. Additionally, 55% of the fish not caught in a fishery re-entered the hatchery in 1999 and 27% either re-entered or remained at the base of the adult return ladder (ladder entrance closed earlier) in 2000. Spring chinook used in this study were of LNFH origin and exhibited a strong preference for downstream not upstream migration. Fish also exhibited a preference for entering the hatchery as opposed to remaining in the lower Icicle.

When tagged steelhead were present in the Icicle above LNFH, April 14 to June 4, 1999 and March 24 to June 9, 2000, the flows ranged from 292-3910 cfs and 190-2830 cfs, respectfully, and the temperatures ranged from 40-45 ^{0}F (4.4-7.2 ^{0}C). Temperatures in both years were 5-17 ^{0}F

below the preferred range of 50 to 57 ^{0}F (10-13.9 ^{0}C) for migration, spawning, and rearing (NMFS 1996). Cold temperatures limit steelhead distribution. Steelhead, with anadromous parents, reared in cold water may residualize because growth is slow and maturity may be reached before smoltification (Mullan *et al.* 1992).

One female steelhead was identified by Chelan Public Utility District in the vicinity of Rock Island Dam approximately 10 days after release. This steelhead may have been a kelt returning to the ocean. Steelhead are iteroparous, they can spawn more than once. Iteroparity occurs predominantly in females (Busby *et al.* 1996) and rarely occurs north of Oregon.

No significant differences in movement were observed between wild and hatchery steelhead. The initial movements of steelhead in this study did not exhibit a preference for either upstream or downstream migration. However, in 1999 55% and in 2000 75% of the tagged fish were in lower Icicle Creek below the hatchery by spawning time. In both years, several tagged steelhead were located near spawning grounds and in 1999 two study fish were located and visually seen on top of redds. Steelhead, spring and summer chinook, and sockeye spawn in lower Icicle Creek. No fish were seen spawning above the hatchery in upper Icicle Creek. Between the hatchery and the "boulder area", spawning sites are extremely limited.

High sediment loads occur and historically occurred in Icicle Creek. One effect of stream sedimentation is a delaying or deterring of salmonid migration. Waters carrying high sediment loads are avoided by migrating salmon or migration ceases if such loads are unavoidable (Cordone and Kelley 1961; in Meehan 1991). A similar response was recorded during this radiotelemetry study. In June 1999, a landslide occurred in the watershed on a flanking slope of the draw that descends from Icicle Ridge and introduced a large quantity of sediment into Icicle Creek. Of 6 radio-tagged steelhead that were in Icicle Creek during the landslide, 2 left the Icicle and entered the Wenatchee River and 4 were never relocated. Of the 5 spring chinook in the stream during the slide, 3 moved downstream to the Wenatchee River and two entered the LNFH ladder. Once the turbid Icicle became clear 2 chinook re-entered Icicle Creek from the Wenatchee River.

In summary, radio tagged fish did not migrate past the natural "boulder area" at river mile 5.6 during the wide range of conditions present at the time. This area is a substantial velocity and gradient fish migration obstacle. Furthermore, natural and man-made obstacles may not be the only limiting factor in fish migration above the Leavenworth National Fish Hatchery. Stream flow, water temperatures, availability of spawning gravel, and sedimentation may also limit upstream migration in Icicle Creek.

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Table 1: Study Fish (Bull Trout) 2000

Fish #	Date Captured and Released	Fork Length (inch)	Weight (lb)	No. of Detections	Dates Detected	Capture Location	Release Location	Upstream Terminous	Last Location
BT1	August 7	16.3	1.93	8	08/9-10/5	LNFH Pool	Canal	Intake	Dryden Dam
BT2	August 11	18.9	3.12	1	08/11	LNFH Pool	Canal	Canal	LNFH Canal
BT3	August 11	15.8	1.55	10	08/21-10/22	LNFH Pool	Canal	Canal	Wenatchee R. (RM 23)
BT4	August 14	19.7	3.1	1	08/16	LNFH Pool	Canal	Intake	LNFH Intake
BT5	August 25	14.6	1.17	1	08/26	LNFH Pool	Intake	Intake	LNFH Intake

Table 2: Study Fish Spring Chinook 1999

Fish #	Date Captured and Released	Fork Length (inch)	No. of Detections	Dates Detected	Capture Location	Release Location	Upstream Terminous	Last Location	Captured
SC1	June 8	29.1	8	06/9-07/06	LNFH Ladder	Canal	LNFH Canal	Wenatchee R (RM 30)	Yes
SC2	June 8	32.7	6	06/18-07/06	LNFH Ladder	Canal	LNFH Canal	Wenatchee R (RM 30)	No
SC3	June 8	32.7	12	06/11-07/08	LNFH Ladder	Canal	LNFH Canal	Wenatchee R (RM 30)	Yes
SC4	June 8	34.3	15	06/14-07/21	LNFH Ladder	Canal	LNFH Canal	LNFH Adult Ponds	Yes
SC5	June 8	30.0	19	06/09-07/21	LNFH Ladder	Canal	LNFH Canal	LNFH Adult Ponds	Yes
SC6	June 22	37.0	6	06/23-07/21	LNFH Ladder	Canal	LNFH Canal	LNFH Adult Ponds	Yes
SC7	June 22	30.3	10	06/23-07/21	LNFH Ladder	Canal	Icicle Ck (RM 3.9)	LNFH Adult Ponds	Yes
SC8	June 22	29.5	7	06/23-07/08	LNFH Ladder	Canal	LNFH Canal	LNFH Pool	No
SC9	June 22	30.3	12	06/23-07/21	LNFH Ladder	Canal	LNFH Canal	LNFH Adult Ponds	Yes
SC10	June 22	30.7	24	06/28-09/13	LNFH Ladder	Canal	Boulder Area	Icicle Creek (RM 2.6)	No
SC11	June 22	41.3	8	06/23-07/12	LNFH Ladder	Canal	LNFH Canal	LNFH Pool	Yes
SC12	June 22	39.0	16	06/23-08/04	LNFH Ladder	Canal	LNFH Canal	LNFH Pool	No
SC13	June 22	31.1	11	06/23-07/21	LNFH Ladder	Canal	Icicle Ck (RM 4.1)	LNFH Adult Ponds	Yes
SC14	June 22	30.0	15	06/23-07/30	LNFH Ladder	Canal	Icicle Ck (RM 5.2)	LNFH Pool	Yes
SC15	June 22	28.4	23	06/23-08/18	LNFH Ladder	Canal	LNFH Canal	Icicle Creek (RM 2.6)	No

Table 3: Study Fish Spring Chinook 2000

Fish #	Date Captured and Released	Fork Length (inch)	No. of Detections	Dates Detected	Capture Location	Release Location	Upstream Terminous	Last Location
SC1	May 24	30.0	27	05/30-09/18	LNFH Ladder	Canal	Icicle Ck (RM 4.1)	Icicle Creek (RM 2.5)
SC2	May 24	31.5	4	05/30-06/09	LNFH Ladder	Canal	Icicle Ck (RM 3.9)	LNFH Pool
SC3	May 24	31.1	2	05/30-06/01	LNFH Ladder	Canal	LNFH Canal	LNFH Pool
SC4	May 24	31.1	9	05/30-06/26	LNFH Ladder	Canal	LNFH Canal	Icicle Creek (RM 1.6)
SC5	May 24	28.0	3	05/30-06/07	LNFH Ladder	Canal	LNFH Canal	LNFH Pool
SC6	June 1	31.1	0	----------	LNFH Ladder	Canal	----------	----------
SC7	June 1	26.4	34	06/05-09/11	LNFH Ladder	Canal	Original Channel	Original Channel
SC8	June 1	30.0	15	06/05-07/12	LNFH Ladder	Canal	LNFH Canal	LNFH Pool
SC9	June 1	30.3	12	06/05-09/18	LNFH Ladder	Canal	LNFH Canal	Icicle Creek (RM 1.6)
SC10	June 1	28.7	35	06/05-09/11	LNFH Ladder	Canal	LNFH Canal	Icicle Creek (RM 2.2)
SC11	June 5	30.7	28	06/07-08/24	LNFH Ladder	Canal	LNFH Canal	LNFH Canal
SC12	June 5	28.7	16	06/07-07/21	LNFH Ladder	Canal	Boulder Area	LNFH Pool
SC13	June 5	31.5	6	06/07-07/28	LNFH Ladder	Canal	LNFH Canal	LNFH Pool
SC14	June 5	27.2	17	06/07-08/21	LNFH Ladder	Canal	LNFH Canal	Dryden Dam
SC15	June 5	30.3	19	06/7-09/18	LNFH Ladder	Canal	Boulder Area	Boulder Area

Table 4: Study Fish (Steelhead) 1999

Fish #	Date Captured and Released	Fork Length (inch)	Sex	Adipose Clipped	Radio Tagged	No. of Detections	Dates Detected	Capture Location	Release Location	Upstream Terminous	Last Location
ST1	April 14	24.0	Male	Yes	Yes	2	04/16-08/11	Ladder	Canal	Icicle Ck (RM 4.5)	Wenatchee R (RM 30)
ST2	April 14	23.6	Female	Yes	Yes	3	04/16-04/20	Ladder	Canal	Icicle Ck (RM 4.5)	Wenatchee R (RM 30)
ST3	April 14	23.2	Male	Yes	Yes	13	04/16-05/26	Ladder	Canal	Boulder Area	Icicle Ck (RM 4.1)
ST4	April 14	23.2	Male	Yes	Yes	10	04/16-05/05	Ladder	Canal	Boulder Area	Icicle Ck (RM 5.2)
ST5	April 14	24.8	Female	Yes	Yes	0	----------	Ladder	Canal	----------	----------
ST6	April 14	24.8	Male	Yes	Yes	13	04/16-06/02	Ladder	Canal	LNFH Canal	Original Channel
ST7	April 19	24.8	Male	Yes	Yes	23	04/20-06/23	Ladder	Canal	Boulder Area	Wenatchee R (RM 30)
ST8	April 19	25.2	Male	No	Yes	12	04/20-06/04	Ladder	Canal	Icicle Ck (RM 4.5)	Original Channel
ST9	April 19	22.4	Male	Yes	Yes	2	04/20-04/22	Ladder	Canal	LNFH Canal	LNFH Canal
ST10	April 19	27.2	Female	Partial	Yes	8	04/20-05/05	Ladder	Canal	Icicle Ck (RM 5.2)	Icicle Creek (RM 5.2)
ST11	April 19	24.0	Female	Yes	Yes	2	04/20-04/28	Ladder	Canal	LNFH Canal	LNFH Canal
ST12	April 19	24.0	Female	Yes	Yes	0	----------	Ladder	Canal	----------	----------
ST13	April 19	24.4	Male	Yes	Yes	1	04/20	Ladder	Canal	LNFH Canal	LNFH Canal
ST14	April 19	23.6	Male	Yes	Yes	21	04/20-06/22	Ladder	Canal	Icicle Ck (RM 4.5)	LNFH Adult Ponds
ST15	April 19	23.6	Female	Yes	Yes	4	04/20-04/28	Ladder	Canal	LNFH Canal	LNFH Pool
ST16	April 26	30.3	Male	Yes	Yes	4	04/28-05/18	Ladder	Canal	LNFH Canal	Icicle Creek (RM 1.6)
ST17	April 26	28.4	Female	No	Yes	24	04/27-07/07	Ladder	Canal	LNFH Canal	Icicle Creek (RM 1.6)
ST18	April 26	23.6	Female	Yes	Yes	2	04/28-05/05	Ladder	Eightmile Cg	Eightmile Cg	Eightmile Cg
ST19	April 26	23.2	Male	Yes	Yes	12	04/29-06/04	Ladder	Eightmile Cg	Eightmile Cg	Eightmile Cg
ST20	April 26	22.4	Female	Yes	Yes	2	05/12-05/13	Ladder	Eightmile Cg	Eightmile Cg	~ 2mi below 8mile Cg
ST21	April 26	23.2	Male	Yes	No	----------	----------	Ladder	Canal	----------	----------
ST22	April 26	22.8	Female	Yes	No	----------	----------	Ladder	Canal	----------	----------
ST23	April 26	22.1	Female	Yes	No	----------	----------	Ladder	Canal	----------	----------
ST24	April 26	22.8	Male	Yes	No	----------	----------	Ladder	Eightmile Cg	----------	----------
ST25	April 26	23.2	Male	Yes	No	----------	----------	Ladder	Eightmile Cg	----------	----------
ST26	April 26	22.4	Female	Yes	No	----------	----------	Ladder	Eightmile Cg	----------	----------
ST27	April 26	15.0	Female	Yes	No	----------	----------	Ladder	Canal	----------	----------
ST28	April 26	16.9	Male	No	No	----------	----------	Ladder	Canal	----------	----------
ST29	April 26	13.4	Female	No	No	----------	----------	Ladder	Canal	----------	----------
ST30	May 7	26.0	Male	Yes	No	----------	----------	Ladder	Eightmile Cg	----------	----------
ST31	May 7	22.8	Female	Yes	No	----------	----------	Ladder	Canal	----------	----------
ST32	May 7	22.8	Female	Yes	No	----------	----------	Ladder	Canal	----------	----------

Table 5: Study Fish (Steelhead) 2000

Fish #	Date Captured and Released	Fork Length (inch)	Sex	Adipose Clipped	Radio Tagged	No. of Detections	Dates Detected	Capture Location	Release Location	Upstream Terminous	Last Location
ST1	March 24	29.5	Male	Yes	Yes	52	03/29-09/18	Ladder	Icicle RV	LNFH Canal	LNFH Pool
ST2	March 29	28.7	Male	Yes	Yes	9	03/31-04/19	Ladder	Icicle RV	Original Channel	Original Channel
ST3	March 29	29.1	Male	Yes	Yes	8	03/31-04/21	Ladder	Icicle RV	LNFH Intake	Mouth of Icicle Creek
ST4	March 29	30.3	Male	Yes	Yes	5	03/31-04/21	Ladder	Icicle RV	Original Channel	Icicle Creek (RM 1.8)
ST5	April 5	30.0	Female	Yes	Yes	20	04/06-09/18	Ladder	LNFH Canal	LNFH Canal	Icicle Creek (RM 2.5)
ST6	April 5	26.8	Female	Yes	Yes	1	Mid-April	Ladder	LNFH Canal	LNFH Canal	Rock Island Dam
ST7	April 5	29.5	Female	Yes	Yes	9	04/10-05/03	Ladder	LNFH Canal	LNFH Canal	Wenatchee R (RM 24.7)
ST8	April 5	28.0	Female	Yes	Yes	7	04/06-04/21	Ladder	LNFH Canal	Original Channel	Original Channel
ST9	April 5	27.6	Female	Yes	Yes	46	04/10-09/18	Ladder	LNFH Canal	LNFH Canal	LNFH Pool
ST10	April 5	29.1	Female	Yes	Yes	1	04/12	Ladder	LNFH Canal	LNFH Canal	Icicle Creek (RM 1.8)
ST11	April 5	26.4	Female	Yes	Yes	9	04/06-04/26	Ladder	LNFH Canal	Original Channel	Original Channel
ST12	April 5	25.6	Male	Yes	Yes	8	04/06-05/01	Ladder	LNFH Canal	Original Channel	Icicle Creek (RM 2.2)
ST13	April 5	27.2	Female	Yes	Yes	10	04/06-06/09	Ladder	LNFH Canal	Boulder Area	Icicle Creek (RM 5.2)
ST14	April 5	22.1	Female	Yes	Yes	2	04/10-04/12	Ladder	LNFH Canal	LNFH Canal	Icicle Creek (RM 1.6)
ST15	April 5	26.4	Male	Yes	Yes	15	04/06-05/10	Ladder	LNFH Canal	Boulder Area	Icicle Creek (RM 5.2)
ST16	April 5	27.2	Female	Yes	Yes	7	04/06-04/21	Ladder	LNFH Canal	LNFH Canal	Wenatchee River
ST17	April 5	28.7	Female	Yes	Yes	2	04/10-04/12	Ladder	LNFH Canal	LNFH Canal	Wenatchee River
ST18	April 13	28.0	Female	Yes	Yes	1	04/19	Ladder	LNFH Canal	Icicle Ck (RM 5.2)	Icicle Creek (RM 5.2)
ST19	April 14	22.8	Male	Yes	Yes	12	04/04-05/10	Ladder	LNFH Canal	Boulder Area	LNFH Intake
ST20	April 14	23.6	Female	Yes	Yes	6	04/04-05/01	Ladder	LNFH Canal	Boulder Area	Icicle Creek (RM 5.2)
ST21	April 13	27.6	Female	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST22	April 13	28.7	Female	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST23	April 13	17.3	Male	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST24	April 17	22.4	Male	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST25	April 17	24.8	Female	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST26	April 17	25.2	Female	No	No	----------	----------	Ladder	LNFH Canal	----------	----------
ST27	April 17	27.6	Female	Yes	No	----------	----------	Ladder	LNFH Canal	----------	----------

Table 6: Creek conditions between the LNFH and the "boulder area" during fish presence[1].

Species	Dates (days) 1999	Range of Flows[2] (cfs) 1999	Range of Temperatures[3] ^{0}F (^{0}C), 1999	Time (days) 2000	Range of Flows[2] (cfs)2000	Range of Temp.[3] ^{0}F (^{0}C), 2000
Bull Trout	NA	NA	NA	8/7-8/21 (15)	167-311	55-60 ^{0}F (12.8-15.6 ^{0}C)
Spring Chinook	6/6-8/18 (74)	539-5900	45-55 ^{0}F (7.2-12.8 ^{0}C)	5/24-8/24 (93)	159-2420	45-60 ^{0}F (7.2-15.6 ^{0}C)
Steelhead	4/14-6/4 (52)	292-3910	40-45 ^{0}F (4.4-7.2 ^{0}C)	3/24-6/9 (78)	190-2830	40-45 ^{0}F (4.4-7.2 ^{0}C)

[1] Presence equals at least one fish above LNFH.

[2] Flows for the Icicle Creek gage, above all diversions, were received from U.S. Geological Survey.

[3] Temperatures readings were collected by USFWS staff from ONSET continuous recorders.